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RESEARCH ARTICLE

Multiplexing efficiency of environmental taxes in ensuring environmental, energy, and economic security

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Abstract

This paper assesses the multiplexing efficiency of environmental taxes in ensuring environmental, energy, and economic security which is an integral part of sustainability in six European countries that are leaders in the Environmental Performance Index. This study aims to confirm the hypothesis that environmental taxes and payments could simultaneously affect changes in important environmental, energy, and economic security as well as sustainability parameters. Not all the previously selected taxes, which affect the parameters of all three areas of environmental, energy, and economic sustainability and security can ensure their simultaneous growth. Calculations made for the period 1994–2019 showed that in the system of environmental taxation of Denmark, five environmental taxes and fees provide an increase in the integrated level of environmental, economic, and energy security and sustainability; in Belgium, two environmental taxes are characterized by multiplex efficiency; in France, seven environmental taxes and payments; in Austria, four; in Finland, one; and in the UK, four. The paper's findings could create the basis for improving environmental taxation systems in the countries to increase comprehensive national security growth and ensure sustainable development path of the countries.

Keywords Environmental tax · Environmental, energy, and economic security · Multiplex effectiveness

Highlights

Multiplexing efficiency of environmental taxes in ensuring environmental, energy, and economic security and sustainability

- This paper assesses six European countries that are leaders in the Environmental Performance Index, 1994–2019.
- Parameters of environmental, energy, and economic security were tested.
- Environmental taxes that virtually ensure the simultaneous growth of security and sustainability are found.
- We confirm the hypothesis that environmental taxes and payments could simultaneously affect changes in security parameters.
- Modeling indicated that not all the selected taxes can ensure their simultaneous growth, measured by an integral indicator.
- This paper puts forward the basis for improving environmental taxation systems.

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Introduction

For decades, the concept of sustainable development has remained a key vector in ensuring the sustainability of the global economy and tackling its global challenges (Bhandari 2019). The dynamics of world development testifies the need to expand the tools for greening the economy at the macro-, meso-, and micro-levels. Ensuring the transition from the industrial to a circular economy should take place based on innovative development and introduction of new technologies (Bilan et al. 2019a, b; Mikhaylova et al. 2019; Tambovceva et al. 2020; Singh 2020), among which eco-innovation (Bunea et al. 2019; Stankevičienė and Nikanorova 2020) and resource efficiency (Razminiene 2019) takes a special place. In addition, it has been proven that higher efficiency in accelerating the transition to a circular economy is demonstrated by increasing environmental responsibility and the growth of investments in environmentally friendly goods and technologies (Lusk and Mook 2020). Technological readiness is defined as a key prerequisite for such a progressive direction of development as a sharing economy (Grybaitė and Stankevičienė 2018). It is important in ensuring the sustainable development of regions (Raszkowski and Bartniczak 2018). Trade liberalization has improved the countries' environmental quality with quite different economic development levels (He 2019).

A balanced concept of the country's innovative development is the key to its economic development and long-term equilibrium (Bachmann and van der Kamp 2014). Green investments also show significant effectiveness in ensuring energy efficiency, as confirmed by empirical research (Pavlyk 2020). In this context, green securities have become widespread (Chygryn et al. 2018; Pimonenko et al. 2020). The critical stimulus for the growth of investments to reduce carbon emissions from energy production is companies' effective energy management systems (Boutti et al. 2019). On the other hand, management factors are crucial in ensuring organizations' sustainable development (Alimuddin et al. 2020; Atkociuniene and Mikalauskiene 2019). In particular, the significant effectiveness is confirmed for green human resource practices (Adeel-Farooq et al. 2021) and sustainable marketing instruments (Vafaei et al. 2019). Despite a wide range of successful instruments for industrial enterprises' environmental management (Chygryn et al. 2020; Sjaifuddin 2018; Vanickova 2020), macroeconomic instruments, particularly investment support, remain the most effective in ensuring sustainable development and stimulating the green economy (Johnson and Mayfield 2020). European countries' experience has shown that under the current environmental and economic threats, the energy sector's balancing inevitably leads to the emergence of distinct patterns in its transformation (Jonek-Kowalska 2019) and developing renewable energy (Cebula et al. 2018). All this confirms the need to balance environmental, economic, and energy effects in the development of national economies and actualizes the search for the effectiveness of tools for their simultaneous ensuring.

The study is based on the hypothesis that the same environmental taxes have different effects on different indicators of environmental, economic, and energy security, which in turn may lead to the leveling of the overall effect achieved in the complex. Thus, the effects of the influence of environmental taxes on each individual component of environmental, economic, and energy security should be combined to determine general effectiveness of environmental taxes. Such pooled effects are defined as the multiplex efficiency of environmental taxes. To assess it, the impact of environmental taxes on individual indicators of environmental, economic, and energy security should be studied, as well as to determine their integrated impact. This determined the sequence of this study in terms of three stages. At the first stage, the sensitivity of certain components of environmental, economic, and energy security to the impact of environmental taxes will be determined. In the second stage, an integrated index of environmental, economic, and energy security is formed, taking into account the sensitivity of individual components, as well as the transmission links that arise between them. At the third stage, the multiplex effectiveness of environmental taxes is assessed by determining their impact on the integrated index of environmental, economic, and energy security.

Literature review

Environmental, energy, and economic security: measuring and interaction

It should be noted that there are numerous scientific approaches to measurement of environmental, energy, and especially economic security. Therefore, comprehensive analysis and generalization of proxies and determinants of environmental, energy, and especially economic security might help to identify the most relevant ones. A significant amount of scientific research confirms the deterioration of the environment under the increasing industrial development scale (Bhatt and Singh 2020; Lyulyov et al. 2015). Consequently, we might consider industry (including construction) value-added annual growth as a relevant indicator of economic security measurement and one of the core determinants of influence on country environmental security. At the same time, the harmful technogenic impact of business on the environment can cause a loss of business reputation and lead to negative synergies between economic and environmental development (Mačaitytė and Virbašiūtė 2018). At the present stage, the company's value is formed under economic factors and considers environmental and social components (Bithas and Kalimeris 2013; Nikodemska-Wołowik et al. 2019; Romana 2020; Drosos et al. 2021). Therefore, a business'

environmental and social responsibilities are prerequisites for ensuring its market competitiveness (Makarenko et al. 2019; Myroshnychenko et al. 2019). Considering the fact that it is rather complicated to measure company corporate social responsibility progress via a single indicator, it is proposed to use research and development expenditure to GDP ratio as a measurement indicator of business technological development and corporate social responsibility potential proxy.

While numerous researchers (Bilan et al. 2018; Boutchouang 2019; Sibanda and Ndlela 2020; Vysochyna et al. 2020a, b) empirically confirmed that country food security might be both a precondition of country environmental sustainability and also could be significantly influenced by environmental determinants, it is necessary to consider such relatively to food security indicators as agriculture land area, forest area, total fisheries production, and fertilizer consumption as one of the core proxies of environmental security. Moreover, the results of studies conducted for Europe, Asia, and South Africa (Bilan et al. 2018; Bhowmik 2019; Sibanda and Ndlela 2020; Vysochyna et al. 2020a, b) empirically confirmed that environmental factors such as CO_2 emissions, methane emissions, nitrous oxide emissions, and total greenhouse gas emissions have an inverse relationship with the level of food security and general country economic sustainability. Therefore, these indicators might be also chosen as proxies of country environmental security. On the other hand, positive synergies characterize the country's food and financial security; their simultaneous growth leads to an overall improvement in its socio-economic development (Boutchouang 2019). Besides, some scientists (Homer-Dixon et al. 1993) argued that intensive population growth over the last few decades triggers both food and environmental security damages. Consequently, population density (people per sq. km of land area) might be considered a core proxy of country environmental security.

The country's economic security largely depends on the national economy's globalization and its integration into the world community (Kubaienko, 2018). That is why an important condition for ensuring the country's economic security is searching for a balanced state of the financial system, which increases the state's resilience to external and internal shocks (Kuzmenko et al. 2020). Therefore, current account balance to GDP ratio should be considered one of measurement indicators of country economic security. One of the key threats to the country's economic security is the increase in the public debt level (Antonov 2018). An essential prerequisite for ensuring the economy's financial and national security is the budget system's transparency, which has a close relationship with fiscal parameters (Molotok 2020). Considering this perspective of scientific debates, it is proposed to choose such indicator as central government debt to GDP ratio as a proxy of country economic security. In addition, the importance of innovation and investment in the country's economic security is determined (Zakharkina et al. 2018). This research strongly supports the idea that gross-fixed-capital-formation-to-GDP ratio and research-and-development-expenditures-to-GDP ratio might become measures of country economic security.

It is founded that socio-economic indicators such as unemployment, income inequality, and GDP per capita determine environmental responsibility and become environmental performance drivers (Holotová et al. 2020; Pryima et al. 2018; Singh 2020). Social and economic indicators are complementary (Bilan et al. 2019a, b; Jafarzadeh and Shuquan 2019), so including socio-economic parameters in economic security characterization provides additional synergy. The necessity to consider socio-economic parameters in electricity pricing is proved (Mentel et al. 2018), reflecting the relationship between national security's economic and energy components. Consequently, it is chosen such social determinants as income share held by lowest 20%, unemployment, and GDP per capita as complementary proxies of country economic security.

Energy security should be evaluated, considering the parameters of energy production, distribution, trade and consumption, and energy productivity and renewables. (Stavytskyy et al. 2018) proposed to choose such indicators of energy production as electricity production from oil, gas, and coal sources; alternative and nuclear-energy-to-total-energy ratio; combustible renewables and waste-to-total-energy ratio; and energy imports, as energy consumption proxies—energy use (kg of oil equivalent) per $1,000 GDP and fossil fuel energy consumption. Researchers also confirmed an interaction between overall energy security and macroeconomic indicators such as GDP and consumer price index. It also confirms the decisive role of renewables in energy security (Kharlamova et al. 2016). Scientists (Vysochyna et al., 2020) also argued that shift from traditional to renewable sources of energy production is highly supported by their difference in negative environmental outputs. Therefore, in the paper, it is also proposed to use as indicators of energy security the following: CO_2 emissions from electricity and heat production and CO_2 intensity (kg per kg of oil equivalent energy use).

The energy sector's development and structure level largely determine the state's economic and environmental security (Wadud et al. 2009). A study (Atta Mills et al. 2020) allowed substantiating bilateral causal relationships between parameters that characterize economic and energy security. In contrast, environmental security indicators depend on economic and energy factors but are not determinants of their change. Another research (Piłatowska and Włodarczyk 2018) confirms the existence of close links between the parameters of environmental, energy, and economic development. Thus, in the short run, CO_2 emissions do not inhibit economic growth, while energy consumption is a significant factor in restoring long-term ecological and economic balance. At the same time,

the close link between value-added in the energy sector and rising greenhouse gas emissions has been confirmed (Chovancová and Tej 2020). All this proves the need to move from a policy focused solely on reducing harmful emissions of production to comprehensive regulation of the energy sector's transformation.

Thus, bilateral relationships in the system "environmental security–energy security–economic security" are confirmed and characterized by both positive and negative synergies that require the use of comprehensive national policy instruments to ensure their simultaneous growth.

Environmental taxes in ensuring countries' national security

While there are numerous publications on identification of measurement indicators of country economic, environmental, and energy security, and its bilateral or multilateral interactions, there is a lack of comprehensive scientific researches aimed at clarification of impact of environmental taxes on country economic, environmental, and energy security as a whole and in terms of its elements. Specifically, it is proven that tax instruments occupy a principal place in implementing economic policy (Boiko and Samusevych 2017; Kobushko and Kobushko 2015; Ślusarczyk 2018; Sokolovska et al. 2020). Therefore, attention should be paid to the results (Koziuk et al. 2019), which prove that environmental regulation tools, including environmental taxes, effectively ensure sustainable development, achieve environmental performance, and maintain a high level of global competitiveness, suggesting multiplex efficiency of environmental taxes. At the same time, Matvieieva et al. (2019) and Xu et al. (2018) prove the significant effectiveness of tax instruments in ensuring the regions' environmental and economic development. Moreover, the confirmed convergence of environmental tax policies (Vysochyna et al. 2020a, b) represents the importance of forming an integrated environmental regulation strategy.

The current trend of global greening ensures its penetration into all components of the economic system. At the same time, the effectiveness of fiscal environmental instruments largely depends on the quality of government regulation, the shadow economy, and oligarchic crony-sector relations (Koziuk et al. 2018). On the other hand, the results (Dkhili 2018; Dkhili and Dhiab 2019) showed that environmental performance depends not only on political but also on institutional and socio-economic factors.

Countries with large reserves of natural resources are characterized by a significantly lower efficiency of the fiscal system and, in particular, limited application of environmental taxes, which proves the existence of an extensive model of economic development, which in strategic terms increases threats to national security (Eddassi 2020). Moreover, the limited natural resources in the country lead to an inverse relationship between their use and financial development (Khan and Kishwar 2020). Thus, it is proved that the current stage of formation of the national development strategy is impossible without the coordination of environmental, economic, and energy policies, which is of particular importance for countries with economies in transition (Djalilov et al. 2015; Rui et al. 2019). Thus, environmental taxes have a significant potential for a comprehensive impact on environmental, energy, and economic security. At the same time, their effectiveness is also determined by existing macroeconomic and institutional preconditions. But these cohesions are not comprehensively researched that proves the necessity of further scientific search in this direction.

Materials and methods

The study aimed to determine the most effective environmental taxes in terms of simultaneous regulation of the country's environmental, energy, and economic security. Given the significant differences in the environmental tax system's construction, calculations are made separately for each country. To form a study sample, we should pay attention to the countries' leaders in the Environmental Performance Index. This index is common in economic research due to its comprehensive description of countries' environments in various manifestations (Bhandari 2013). It is expected that the leading countries in the index have a significant level of effectiveness of environmental tax policy. Thus, considering the ranking positions, the sample was formed from 6 European countries (Belgium, Denmark, France, Austria, Finland, and the UK). We choose the amount of tax revenues from each of the environmental taxes presented in the country as the parameters of environmental taxation. In order to maintain the proportionality of the obtained dependencies, environmental taxes applied in certain cities or regions of the country were excluded from the sample. Environmental, energy, and economic security are complex categories, so for their description, a set of components was selected, the use of which is justified by existing theoretical and empirical studies (Table 1). The study period covers 1994–2019.

At the first stage of the study, the list of environmental taxes that can significantly impact the simultaneous provision of all three components of national security (environmental, energy, and economic security) should be substantiated Data of environmental taxes was collected from OECD Database on Policy Instruments for the Environment (2020). To do this, a Granger causality test was performed, which allows not only to determine the relationship between indicators and define the nature of the interaction of indicators in terms of unilateral or bilateral causal relationships. The Granger test to diagnose the relationships between different phenomena has become

Table 1 Components of environmental, energy, and economic security and sustainability

Environmental security indicators		Energy security indicators		Economic security indicators	
Env1	Agricultural land, % of land area	Eng1	CO_2 emissions from electricity and heat production, % of fuel combustion	Ecn1	Central government debt, total % of GDP
Env2	Forest area, % of land area	Eng2	CO_2 intensity, kg per kg of oil equivalent energy use	Ecn2	GDP growth, annual %
Env3	CO_2 emissions, metric tons per capita	Eng3	Electricity production from oil, gas, and coal sources, % of total	Ecn3	GDP per capita, PPP constant 2011 international $
Env4	Methane emissions, % change from 1990	Eng4	Energy imports, net % of energy use	Ecn4	Gross fixed capital formation, % of GDP
Env5	Nitrous oxide emissions, % change from 1990	Eng5	Oil rents, % of GDP	Ecn5	Income share held by lowest 20%
Env6	Population density, people per sq. km of land area	Eng6	Alternative and nuclear energy, % of total energy use	Ecn6	Industry value-added, annual % growth
Env7	Fertilizer consumption, kilograms per hectare of arable land	Eng7	Combustible renewables and waste, % of total energy	Ecn7	Research and development expenditure, % of GDP
Env8	Total fisheries production growth, annual %	Eng8	Energy use (kg of oil equivalent) per $1,000 GDP	Ecn8	Unemployment, % of the total labor force
Env9	Total greenhouse gas emissions, % change from 1990	Eng9	Fossil fuel energy consumption, % of total	Ecn9	Current account balance, % of GDP

Source of data—the World Bank World Development Indicators database (World Development Indicators 2020)

widespread in economic research (Atta Mills et al. 2020; Bilan et al., 2020; Skare and Porada-Rochoń 2019). In this study, the Granger test was performed in Stata 12/SE software. At the first stage, Vector autoregression models were built for each of the pairs "environmental tax – an indicator of environmental (economic, energy) security" by country. The maximum duration of the time lag in the models is determined as 2 years. Based on the results of the built VAR models, Granger causality Wald tests were conducted using economic and mathematical tools Stata 12/SE. The statistical significance of the results was determined by the values of χ^2 and Prob> χ^2 criteria. The calculations were based on assessing pairwise causal relationships between each environmental tax and environmental, energy, and economic security components. This stage's result was selecting effective environmental taxes, which simultaneously impact most of the selected national security indicators.

At the second stage, an integrated indicator of environmental, energy, and economic security was formed. This stage includes selecting the general list of the three security areas sensitive to the effects of environmental taxes (characterized by causal dependence in most cases). Given the different dimensions of the selected indicators, they were normalized by natural normalization (for stimulants) and Savage normalization (for destimulants).

The selection of national security indicators dependent on the impact of environmental taxes allowed identifying significant differences in the level of such dependence. Therefore, the integrated indicator's formation should be carried out considering the weights for each environmental, energy, and economic security parameter. In contrast to Shkolnyk et al. (2020), which use the Fishburne method in determining the weights of the integrated indicator of financial security, we propose to apply the method of analytical hierarchy, which provides for the formation of a general rating of indicators based on their pair ratios that will consider transmission relationships between environmental tax parameters and environmental, economic, and energy security indicators. The criterion for forming hierarchical pairs of environmental, economic, and energy security components was the number of Granger test results, which confirms the dependence of each of the indicators on environmental taxes selected at the previous stage of the study. At this stage, the integrated characteristics of environmental, economic, and energy security were formed by additive-multiplicative convolution, taking into account determined weights.

Completion of this stage involves the construction of an integrated indicator that summarizes the 3 levels of security. It is determined that the construction of an integrated indicator that describes the related categories should be based on the definition of each component's integrated level and taking into account the relationships between its components (Vasilyeva et al. 2019). With this in mind, the integrated

indicator of environmental, economic, and energy security was constructed using nonlinear additive-multiplicative convolution by the Kolmogorov-Gabor method. Thus, the generalized formula for determining the integrated indicator looks like this:

$$INT = \sum_{i=1}^{I} w_i \bullet Env_i + \sum_{j=1}^{J} w_j \bullet Eng_j + \sum_{k=1}^{K} w_k \bullet Ecn_k + \sum_{i=1}^{I} w_i \bullet Env_i + \sum_{j=1}^{J} w_J \bullet Eng_j + + \sum_{i=1}^{I} w_i \bullet Env_i + \sum_{k=1}^{K} w_k \bullet Ecn_k + \sum_{j=1}^{J} w_J \bullet Eng_j \bullet \sum_{k=1}^{K} w_k \bullet Ecn_k + + \sum_{i=1}^{I} w_i \bullet Env_i \bullet \sum_{j=1}^{J} w_J \bullet Eng_j \bullet \sum_{k=1}^{K} w_k \bullet Ecn_k \quad (1)$$

where $w_{i,j,k}$ is the weights of the ith indicator of environmental security, jth energy security indicator, and kth indicator of economic security; Env_i, Eng_j, and Ecn_k are the normalized values of the ith indicator of environmental security, jth energy security indicator, and kth indicator of economic security.

At the third stage of the study, we modeled environmental taxes' impact on the integrated level of environmental, economic, and energy security. Before performing the calculations, a Dickey-Fuller test for stationary time series was performed. Given the different amounts of environmental taxes in each country, the assessment was conducted separately for each country, using the base specification of the least squares model. Revenues from each of the environmental taxes were chosen as factors in each model. Accordingly, for each country, a set of models has been built that corresponds to the number of effective environmental taxes previously selected. The need to take into account the additional conditions of operation in the country, which mediate the impact of environmental taxes on the integrated indicator of environmental, economic, and energy security, indicates the feasibility of including in the model a number of control variables:

(1) Inflation (consumer price index, relative to the level of 2010). Inflation is expected to reduce the effects of environmental taxes, as some of the indicators included in the integrated indicator of environmental, economic, and energy security have monetary measures.
(2) Trade openness (the difference between exports and imports, % of GDP). This indicator reflects the intensity of foreign economic relations of the state, which, on the one hand, can identify threats to national security, and on the other, to increase its level for export-oriented countries.
(3) Control of corruption (World Governance Indicator). An indicator that reflects public relations within the country in terms of perceptions of corruption. It is expected that the growth of this indicator is a factor that strengthens national security, and, accordingly, is a prerequisite for increasing the multiplex efficiency of environmental taxes.
(4) Government effectiveness (World Governance Indicator). It is traditionally believed that the growth of this indicator increases the efficiency of all processes in the state, so in the models it is considered an enhancer of the impact of environmental taxes on the integrated indicator of environmental, economic, and energy security.
(5) Regulation quality (World Governance Indicator). Like previous indicators, this indicator is a prerequisite for increasing the effectiveness of regulatory instruments, which include environmental taxation.

The statistical basis for the selected control variables was the data of the World Bank.

Analysis of the constructed equations allows to determine in each country exactly those environmental taxes that have multiplex efficiency in terms of impact on the integrated indicator of environmental, economic, and energy security.

Results

Selection of environmental taxes, which are potentially useful in multiplex regulation of environmental, energy, and economic security

Thus, determining the causality between individual environmental taxes and the dynamics of environmental, economic, and energy security indicators in Denmark are shown in Table 9 in the Appendix. Unfortunately, the statistical database for Denmark did not allow a Granger test to determine the impact of environmental taxes on such an indicator of economic security as central government debt (Ecn1). It should be noted that, despite the considerable number and diversification of environmental taxes in Denmark, only some of the studied taxes and environmental payments were significant in terms of their use to ensure environmental, energy, and economic security. Thus, set of environmental taxes, which have a causal relationship with most of the studied indicators of environmental, energy, and economic security in Denmark includes the following: passenger duty, duty on coal, duty on electricity, duty on pesticides, duty on tires, and sale of vehicle number plates.

On the other hand, attention should be paid to those environmental taxes and fees that do not have a strong potential for multiplexing the impact on national security. However, they are determinants of individual channels of its provision. In particular, duty on polyvinyl chloride and phthalates, duty on certain chlorinated solvents, and duty on electric bulbs and electric fuses do not affect environmental security components; however, they are determinants of specific energy and economic security components. In contrast, duty on sealed NiCd batteries and motor vehicle registration duty can simultaneously impact environmental and economic security components. Waste duty can only be an instrument of

state policy on energy security. The rest of the studied taxes and payments in Denmark can simultaneously affect the components of all three areas of national security. However, the complexity of such effects is insufficient in terms of maximizing their multiplex efficiency.

Compared to other sample countries, Belgium's environmental tax system is characterized by a few taxes and fees. The evaluation results presented in Table 10 in the Appendix showed that the most comprehensive effect of the simultaneous provision of environmental, energy, and economic security in Belgium could provide the Environmental charge and APETRA contribution. At the same time, FAPETRO contribution demonstrates only energy and economic effects, and Tax on industrial waste has environmental and energy regulatory value. The rest of the presented taxes have a weak potential for multiplex impact on environmental, economic, and energy security. However, they can ensure their regulation through separate channels. Note that Belgium's statistical database did not allow the Grander test to determine the impact of environmental taxes on several energy security indicators (Eng5) and economic security (Ecn1).

The assessment of the dependence of environmental, economic, and energy security components on environmental taxes in the UK (Table 11 in the Appendix) identified four environmental taxes that can be most effective in comprehensive ensuring national security (air passenger duty, air travel organizer license fees, landfill tax, renewable energy obligations). Other environmental taxes and fees (except water regulator fees) are of limited effectiveness and can be used in specific objectives of state environmental, energy, and economic policies. Water regulator fees are only suitable for ensuring the progress of energy and economic security.

The results of the assessment of the causal links between environmental taxes and national security parameters in France (Table 12 in the Appendix) showed a fairly wide range of environmental taxes that can provide multiplexing efficiency in ensuring environmental, economic, and energy security. The list of effective environmental taxes includes CO_2-related malus system for motor vehicle registrations, contribution to electricity generators for public services they provide, domestic tax on final electricity consumption, domestic tax on natural gas, mining taxes, special fuel tax in communities overseas, tax due by airlines and shipping in Corsica and overseas departments, tax on electricity pylons, and household refuse collection tax. In general, it can be noted that the system of environmental taxes in France is quite effective. Thus, the rest of the studied taxes also have a simultaneous impact on the indicators of the three components of national security (except for dock dues, which do not affect the parameters of economic security). However, such dependencies are not comprehensive enough to select these taxes for another modeling.

A study of the Austrian environmental tax system (Table 13 in the Appendix) showed that 5 out of 19 analyzed taxes could be effective regulators of the integrated level of environmental, energy, and economic security. Such taxes were duty on vehicles (based on fuel consumption), recurrent taxes on motor vehicles, tax on mineral oils, road pricing for lorries for the use of highways, and wastewater charges. Among other taxes, we should pay attention to the waste deposit levy, which changes only the level of environmental and economic security. The remaining taxes have a comprehensive limited impact on all three studied national security components and can be used in research to ensure specific vectors of its development.

The calculations performed for Finland (Table 14 in the Appendix) allowed determining a wide range of environmental taxes with high multiplexing efficiency. Thus, the sample of further research includes 10 taxes and fees: fishing license fees, charge on tires, excise on fuels and electricity, nuclear energy research levy, oil damage levy, registration fee of vehicles, vehicle tax, charge on municipal waste collection/treatment, charge on nuclear waste, water user charges. In terms of other taxes, we note only the railway tax does not have the potential for multiplex efficiency, affecting only environmental security indicators.

Construction of integral indicator of environmental, energy, and economic security

Integrated assessment of environmental, energy, and economic security involves the formation of their generalizing characteristics. For further evaluation, only those indicators of environmental, energy, and economic security were selected for which in most cases the Granger test showed the sensitivity of the indicator to the impact of environmental taxes. Thus, for the construction of the integrated indicator, the environmental security indicators Env3-Env9 are taken into account; energy security indicators Eng1-Eng4 and Eng7-Eng9; and indicators of economic security Ecn2, Ecn5, Ecn6, and Ecn9. The sensitivity of a single indicator of environmental, energy, and economic security to the impact of environmental taxes defines its importance for determining the multiplex effectiveness of environmental taxes. For this purpose, the weights of the constituent components of environmental, energy, and economic security were determined using the method of analytical hierarchy. This method involves the construction of "hierarchical pairs"—the relationship between two indicators, which presents the priority of one indicator over another. The criterion for the formation of hierarchical pairs is the absolute number of cases in which the Granger test determined the sensitivity of each indicator of environmental (energy, economic) security to the impact of environmental taxes (based on the results of Tables 9–14 in the Appendix). Table 2 shows the ratio of sensitivity between each of the two environmental security indicators, the sum of such ratios for

Table 2 Identifying of weights of environmental security and sustainability indicators based on the method of analytical hierarchy

Indicators	Env3	Env4	Env5	Env7	Env8	Env9	Weights
Env3	1,000	0,667	0,733	0,767	0,633	0,700	0,222
Env4	1,500	1,000	1,100	1,150	0,950	1,050	0,148
Env5	1,364	0,909	1,000	1,045	0,864	0,955	0,163
Env7	1,304	0,870	0,957	1,000	0,826	0,913	0,170
Env8	1,579	1,053	1,158	1,211	1,000	1,105	0,141
Env9	1,429	0,952	1,048	1,095	0,905	1,000	0,156
Sum	8,176	5,450	5,995	6,268	5,178	5,723	1,000

each indicator, as well as the weights for each indicator, which in total are equal to 1.

Integrated levels of energy and economic security were determined by the same method. The generalized levels of ecological, energy, and economic security, as well as their integrated indicator in the context of European countries are shown in Figure 1. It should be noted that during the study period there is a general increase in the integrated level of environmental, economic, and energy security in all countries studied. However, in the context of the period, the indicator is characterized by a significant level of volatility. We can even note the cyclical dynamics of national security's integrated level with different cycle lengths for each studied country. Simultaneously, the dynamics of individual components of the integrated level of environmental, economic, and energy security were characterized by significant differences for each of the studied countries. Thus, environmental security in France and Finland is characterized by general growth with little cyclicality during the study period, while in other countries there is a linear growth trend. Energy security is growing quite significantly in all countries except the UK, where a certain average level is maintained during the period. Economic security has declined significantly during the study period in France, Finland. and Belgium, while in Denmark, Austria, and the UK it remains at a certain average level.

Essential differences in the trends of the integrated level of national security and its components in different countries

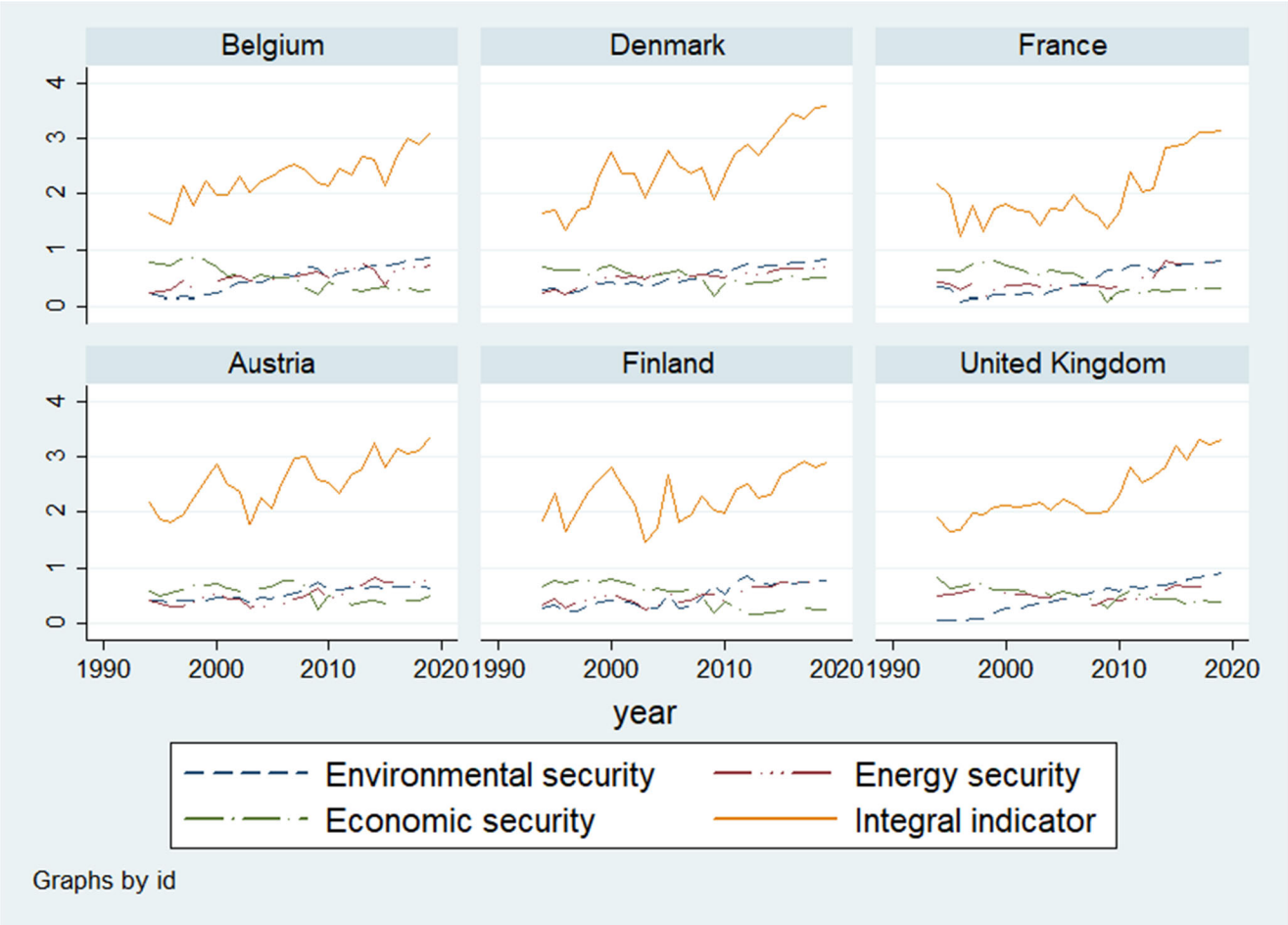

Fig. 1 Level of integral indicator of environmental, energy, and economic security and its components for European countries during 1994–2019

Table 3 Results of the evaluation of multiplex efficiency of environmental taxes in Denmark

Variable	Coef. on factor variable	Coef. on control variables				*F* (prob > *F*)
		Government effectiveness	Regulatory quality	Trade openness	Inflation	
Passenger duty	−0.0116*** (0.0027)	1.8688*** (0.4593)	−6.1933*** (1.4744)	0.1038* (0.0589)	0.1297 (0.1184	8.54 (0.0003)
Duty on coal	0.0029*** (0.0008)	0.4917 (0.5149)	−5.0868*** (1.1741)	−0.0151 (0.0761)	0.0889 (0.1281)	10.78 (0.0000)
Duty on electricity	0.0009*** (0.0001)	0.3467 (0.4342)	−3.8616*** (0.9180)	0.0518 (0.0565)	0.0708 (0.1022)	16.86 (0.0000)
Duty on pesticides	0.0131*** (0.0028)	−0.0218 (0.5063)	−3.3815*** (0.9816)	0.0692 (0.0599)	0.0129 (0.1061)	14.07 (0.0000)
Duty on tires	0.1491*** (0.0322)	−0.1668 (0.5301)	−3.9824*** (1.0926)	0.0124 (0.0651)	0.0772 (0.1134)	11.50 (0.0000)
Sale of vehicle number plates	0.0115*** (0.0029)	0.6434 (0.4695)	−3.1219** (1.3826)	0.1186* (0.0602)	0.1141 (0.1189)	6.02 (0.0026)

*Significance level at 0.10 level; **significance level at 0.05 level; ***significance level at 0.01 level; standard error in the brackets

confirm the necessity to assess the impact of environmental taxes on national security for each country.

Assessment of environmental taxes multiplexing efficiency in ensuring environmental, energy, and economic security

The results of the evaluation of the multiplex effectiveness of the selected environmental taxes in Denmark (Table 3) showed that almost all of the studied taxes have a significant potential to simultaneously stimulate environmental, energy, and economic security.

It should be noted that the growth of duty on tires in the equivalent of $ 1 million, on average, determines an increase in the integrated level of environmental, energy, and economic security by 0.1491, which indicates the high multiplex efficiency of this environmental tax. At the same time, it should be noted that passenger duty is not effective in ensuring multiplex growth of environmental, energy, and economic security—the growth of tax revenues from this environmental tax leads to a reduction in its integral level. Finally, assessing the impact of control variables, we note that in some cases, government effectiveness and trade openness are stimulators of growth of the level of integral indicator of environmental, energy, and economic security, and regulatory quality is a factor that reduces its level.

In the UK, all selected environmental taxes have multiplex effectiveness in ensuring an integral level of environmental, economic, and energy security (Table 4).

At the same time, the most extensive level of influence has Air travel organizer license fees, while the rest of the taxes are characterized by a similar level of quantitative effects. However, the control of corruption and trade openness provide additional incentives for the growth of national security's multiplex effectiveness.

Table 4 Results of the evaluation of multiplex efficiency of environmental taxes in the UK

Variable	Coef. on factor variable	Coef. on control variables				*F* (prob > *F*)
		Control of corruption	Government effectiveness	Regulatory quality	Trade openness	
Air passenger duty	0.0002*** (0.0000)	1.9667*** (0.4210)	−1.1596** (0.5407)	−0.8460 (0.5532)	0.1095 (0.0733)	21.00 (0.0000)
Air travel organizer license fees	0.0113*** (0.0018)	1.5699*** (0.3774)	−1.0722** (0.4945)	−0.0726 (0.5061)	−0.0699 (0.0679)	25.82 (0.0000)
Landfill tax	0.0006*** (0.0001)	2.9575*** (0.6668)	−2.7371*** (0.5445)	−0.4823 (0.6882)	0.2269** (0.1063)	11.97 (0.0000)
Renewable energy obligations	0.0002*** (0.0000)	0.3870 (0.3851)	0.3244 (0.5941)	−0.8731* (0.4695)	0.0467 (0.0611)	30.62 (0.0000)

*Significance level at 0.10 level; **significance level at 0.05 level; ***significance level at 0.01 level; standard error in the brackets

Table 5 Results of the evaluation of multiplex efficiency of environmental taxes in France

Variable	Coef. on factor variable	Coef. on control variables		*F* (prob > *F*)
		Regulatory quality	Inflation	
CO_2-related malus system for motor vehicle registrations	0.0019*** (0.0006)	−0.4856 (0.7913)	−0.1024 (0.1415)	2.51 (0.0063)
Contribution to electricity generators for public services they provide	0.0002*** (0.0000)	−1.3065** (0.5334)	0.1062 (0.0951)	25.47 (0.0000)
Domestic tax on final electricity consumption	0.0006** (0.0002)	−0.9761 (1.0848)	−0.0959 (0.1641)	3.25 (0.0421)
Domestic tax on natural gas	0.0027*** (0.0009)	−1.0077 (0.7868)	0.0682 (0.1479)	3.94 (0.0264)
Mining taxes	−0.0124 (0.0075)	−0.4964 (1.0594)	−0.1891 (0.1609)	2.68 (0.0746)
Special fuel tax in communities overseas	0.0009 (0.0016)	0.0377 (1.3751)	−0.2839* (0.1615)	1.67 (0.2044)
Tax due by airlines and shipping in Corsica and overseas departments	0.0175*** (0.0059)	−1.1742 (1.0409)	−0.1161 (0.1531)	4.25 (0.0178)
Tax on electricity pylons	0.0052** (0.0019)	−1.5307 (1.1556)	−0.0777 (0.1601)	3.82 (0.0249)
Household refuse collection tax	0.0002** (0.0000)	−1.4764 (1.1419)	−0.1137 (0.1554)	4.05 (0.0211)

*Significance level at 0.10 level; **significance level at 0.05 level; ***significance level at 0.01 level; standard error in the brackets

At the same time, government effectiveness and regulatory quality proved to be factors holding back the level of national security.

The assessment of the impact of environmental taxes on the integral level of environmental, economic, and energy security in France (Table 5) showed that tax due by airlines and shipping in Corsica and overseas departments has the greatest multiplex potential. In addition, CO_2-related malus system for motor vehicle registrations, contribution to electricity generators for public services they provide, domestic tax on final electricity consumption, domestic tax on natural gas, tax on electricity pylons, and household refuse collection tax are effective in ensuring comprehensive growth of national security. On the other hand, environmental taxes such as mining taxes and special fuel tax in communities overseas are not effective tools for the simultaneous growth of environmental, economic, and energy security. The studied control variables did not turn out to be significant factors in forming the impact of environmental taxes on national security.

The results of modeling the impact of environmental taxes in Belgium on the integral level of environmental, economic, and energy security (Table 6) showed that a significant multiplexing efficiency level characterizes both selected taxes. At the same time, the growth of tax revenues from the environmental charge allows achieving a larger increase in the integral level of national security than the increase in revenues from the APETRA contribution. Regarding the influence of control variables, it can be noted the lack of significant additional regulatory effect.

In the Austrian environmental tax system, 4 instruments (recurrent taxes on motor vehicles, tax on mineral oils, road pricing for lorries for the use of highways, wastewater

Table 6 Results of the evaluation of multiplex efficiency of environmental taxes in Belgium

Variable	Coef. on factor variable	Coef. on control variables		*F* (prob > *F*)
		Regulatory quality	Inflation	
Environmental charge	0.0167** (0.0078)	1.2413 (0.7371)	0.6320 (0.8782)	3.01 (0.0560)
APETRA contribution	0.0018** (0.0007)	−0.0428 (0.0665)	0.0068 (0.0750)	3.33 (0.0393)

*Significance level at 0.10 level; **significance level at 0.05 level; ***significance level at 0.01 level; standard error in the brackets

Table 7 Results of the evaluation of multiplex efficiency of environmental taxes in Austria

Variable	Coef. on factor variable	Coef. on control variables		*F* (prob > *F*)
		Regulatory quality	Inflation	
Duty on vehicles (based on fuel consumption)	0.0011 (0.0009)	−1.3250 (1.0804)	0.0024 (0.1325)	1.12 (0.3654)
Recurrent taxes on motor vehicles	0.0004*** (0.0001)	−0.1376 (0.8689)	−0.0167 (0.0967)	7.54 (0.0013)
Tax on mineral oils	0.0002** (0.0001)	−0.6826 (1.0403)	−0.0187 (0.1197)	4.60 (0.0402)
Road pricing for lorries for the use of highways	0.0004*** (0.0001)	−0.4112 (0.8797)	−0.0369 (0.1017)	6.53 (0.0027
Wastewater charges	0.0005* (0.0002)	0.0882 (1.0459)	0.0314 (0.1277)	1.50 (0.2602)

*Significance level at 0.10 level; **significance level at 0.05 level; ***significance level at 0.01 level; standard error in the brackets

charges) have a similar level of impact on the integrated level of environmental, energy, and economic security (Table 7). The increase in the amount of tax revenues of each of these taxes and payments leads to an increase in the integral indicator of national security's three components. On the other hand, duty on vehicles (based on fuel consumption) does not have a sufficient statistical significance level to ensure comprehensive national security regulation.

Attention should be paid to the results of the assessment of the impact of environmental taxes on the integral level of environmental, energy, and economic security obtained for Finland (Table 8). Thus, out of 10 selected environmental taxes and payments, only vehicle tax demonstrates multiplex efficiency in the simultaneous provision of all three areas of national security. On the other hand, fishing license fees proved to be statistically significant; however, the inverse link

Table 8 Results of the evaluation of multiplex efficiency of environmental taxes in Finland

Variable	Coef. on factor variable	Coef. on control variables		*F* (prob > *F*)
		Regulatory quality	Government effectiveness	
Fishing license fees	−0.0421* (0.0234)	1.0513* (0.6039)	−0.2602 (0.3158)	3.05 (0.0509)
Charge on tires	0.0132 (0.0465)	0.4865 (0.9719)	−0.4867 (0.3878)	0.63 (0.6091)
Excise on fuels and electricity	0.0001 (0.0000)	1.0812* (0.6056)	−0.6346* (0.3191)	2.91 (0.0582)
Nuclear energy research levy	0.0349 (0.0160)	1.0237* (0.5826)	−0.5691* (0.2939)	3.69 (0.0280)
Oil damage levy	0.0014 (0.0086)	1.3111* (0.6557)	−0.0463 (0.3321)	1.73 (0.1923)
Registration fee of vehicles	−0.0007 (0.0066)	0.8171 (0.8661)	−0.5441 (0.3778)	1.21 (0.3355)
Vehicle tax	0.0004* (0.0002)	1.0328 (0.6054)	−0.5704* (0.3048)	3.08 (0.0495)
Charge on municipal waste collection/treatment	0.0005 (0.0015)	0.9107 (0.6189)	−0.3173 (0.3575)	0.80 (0.5085)
Charge on nuclear waste	0.0031 (0.0027)	0.1714 (0.9108)	−0.5696 (0.3620)	1.13 (0.3735)
Water user charges	0.0001 (0.0009)	0.9362 (0.6756)	−0.2876 (0.3951)	0.67 (0.5810)

*Significance level at 0.10 level; **significance level at 0.05 level; ***significance level at 0.01 level; standard error in the brackets

indicates the inexpediency of using this tax as an effective tool for simultaneous environmental, energy, and economic security due to the negative synergy of the effects.

The impact of other taxes on the integral level of environmental, energy, and economic security was statistically insignificant, which does not allow their use as tools of a comprehensive national security strategy. At the same time, the previously identified causal relationships indicate that these environmental tax instruments can be successfully used to achieve certain goals of state environmental, energy, and economic policy.

Research concerns and challenges

Analysis of the experience of European countries shows that despite the general trends towards harmonization of tax legislation, there are significant national differences in the composition and structure of environmental taxes. In the analyzed European countries, there are more than 10 specific kinds of environmental taxes but all the variety of them might be aggregated in three groups: energy taxes, transport taxes, and emissions and resource taxes. It should be noted that energy taxes have the largest fiscal potential and ensure the biggest volume of tax revenues, the second place in the general structure of total tax revenues are ensured by transport taxes, while taxes on resources and pollution provide a small share of tax revenues in total. These groups of environmental taxes also have significant impact on three dimensions of national security (economic, environmental, and energy) but such an influence varies in different countries. In general, it can be concluded that specifically transport taxes and energy taxes have higher potential of multiple and transmission effect on all three dimension of national security, while taxes on resources and pollution are more relevant in terms of environmental and energy security. Considering cost-effective and eco-effective proxies, it can be concluded that waste taxes has the greater potential in terms of implementation of cyclical economy approach (Kyriakopoulos 2021). Scientists argued that the most common recent environmental innovation at small- and medium-sized enterprises are implementation of ISO 14001 management systems and the toxic substances usage reduction (Skordoulis et al. 2020). Therefore, we can conclude that different types of environmental taxes have different levels of effectiveness in terms of its fiscal potential, regulatory potential, cost-effectiveness and eco-effectiveness. Consequently, assessment of cumulative effectiveness of energy taxes, transport taxes, and emissions and resource taxes in terms of eliminating damages for national security via different channels forms the perspective of further research.

Conclusions

The study proposed and confirmed the hypothesis that environmental taxes and payments could simultaneously affect changes in environmental, energy, and economic security components. Certain environmental taxes have different levels and scales of impact on the three components of national security. The Granger test application allowed a selection of a list of environmental taxes that have the most comprehensive and simultaneous impact on ensuring the most environmental, energy, and economic security components. The list of selected environmental taxes and payments with the potential for multiplex effectiveness in guaranteeing national security varies from two to ten environmental tax instruments in terms of 6 studied European countries. To assess the multiplex effectiveness of environmental taxes, an integrated indicator of environmental, energy, and economic security was developed, which combines the components most sensitive to environmental taxes, considering the weights that characterize the level of such sensitivity. Modeling of multiplex effects of environmental taxes showed that not all the previously selected taxes, which affect the components of all three areas of environmental, energy, and economic security, can ensure their simultaneous growth, measured by an integral indicator. Thus, for each country, environmental taxes have been identified that have multiplexing efficiency in the simultaneous provision of environmental, energy, and economic security: (1) in Denmark, such taxes include duty on tires, duty on pesticides, sale of vehicle number plates, duty on coal, duty on electricity; (2) in the UK, this function can be performed by four environmental taxes: air passenger duty, air travel organizer license fees, landfill tax, renewable energy obligations; (3) in France, environmental taxes with multiplexing efficiency are defined as CO_2-related malus system for motor vehicle registrations, contribution to electricity generators for public services they provide, domestic tax on final electricity consumption, domestic tax on natural gas, tax due by airlines and shipping in Corsica and overseas departments, tax on electricity pylons, household refuse collection tax; (4) in Belgium, both environmental charge and APETRA contribution are effective; (5) recurrent taxes on motor vehicles, tax on mineral oils, road pricing for lorries for the use of highways, and wastewater charges have been identified as effective in Austria; (6) in Finland, only vehicle tax has multiplexing efficiency in ensuring environmental, energy, and economic security.

The obtained results create a basis for adjusting national environmental taxation systems taking into account their impact on national security. Thus, inefficient environmental taxes should be abolished or improved in such a way that positive multiplex effects are achieved as a result of their operation. At the same time, effective environmental taxes should be central to the implementation of state environmental and economic policies.

Appendix

Table 9 Results of Granger causality test for the dependence of environmental, energy, and economic security and sustainability indicators on environmental taxes in Denmark

Environmental tax	Environmental security indicators		Energy security indicators		Economic security indicators	
	D	ND	D	ND	D	ND
Duty on lead accumulators	Env4, 6, 7	Env1-3, 5, 8, 9	Eng5	Eng1-4, 6-9	Ecn2, 4, 6, 8	Ecn3, 7, 9
Duty on polyvinyl chloride and phathalates	–	Env1-9	Eng1, 4	Eng2, 3, 5-9	Ecn5, 9	Ecn2-4, 6-8
Passenger duty	Env3, 4, 8, 9	Env1, 2, 5, 6	Eng1, 2, 5, 8, 9	Eng3, 4, 6, 7	Ecn2-4, 8, 9	Ecn6, 7
Tax on mineral phosphorous in feed phosphates	Env1, 4, 5, 7	Env2, 3, 6, 8, 9	Eng4	Eng1-3, 5-9	Ecn5-9	Ecn2-4
Duty on carrier bags made of paper, plastics, etc.	Env2, 7	Env1, 3-6, 8, 9	Eng4	Eng1-3, 5-9	Ecn6	Ecn2-5, 7-9
Duty on pesticides	Env1, 3, 5, 7-9	Env2, 4, 6	Eng1, 2, 4, 7-9	Eng3, 5, 6	Ecn5, 6, 9	Ecn2-4, 7, 8
Duty on petrol	Env5	Env1-4, 6-9	Eng4, 5, 7	Eng1-3, 6, 8-9	–	Ecn2-9
Duty on piped water	Env1, 3, 5, 9	Env2, 4, 6-8	Eng1, 2, 8, 9	Eng3-7	Ecn6, 9	Ecn2-5, 7, 8
Duty on public service obligations	Env4, 7	Env1-3, 5, 6, 8, 9	Eng5	Eng1-4, 6-9	Ecn3, 9	Ecn2, 4-8
Duty on PVC film	Env2, 4, 5, 7	Env1, 3, 6, 8, 9	Eng4	Eng1-3, 5-9	Ecn2, 3, 7, 9	Ecn4-6, 8
Duty on raw materials	Env2	Env1, 3-9	Eng6	Eng1-5, 7-9	Ecn2-4, 6-9	Ecn5
Duty on sealed NiCd batteries	Env1	Env2-9	–	Eng1-9	Ecn4, 8, 9	Ecn2, 3, 5-7
Duty on sulfur	Env3, 8	Env1, 2, 4-7, 9	Eng4, 5, 8	Eng1-3, 6, 7, 9	Ecn6	Ecn2-5, 7-9
Duty on tires	Env1, 2, 4, 6, 8, 9	Env3, 5,	Eng1, 4, 7	Eng2, 3, 5, 6, 8, 9	Ecn5-8	Ecn2-4, 9
Duty on waste	–	Env1-9	Eng3, 6	Eng1, 2, 4, 5, 7-9	–	Ecn2-9
Duty on waste water	Env4	Env1-3, 5-9	Eng5	Eng1-4, 6-9	Ecn7	Ecn2-6, 8, 9
Fee on a fishing permit	Env2-6	Env1, 7-9	Eng1, 4, 7	Eng2, 3, 5, 6, 8, 9	Ecn9	Ecn2-8
Fee on hunting license	Env2, 4, 5, 7, 8	Env1, 3, 6, 9	Eng4	Eng1-3, 5-9	Ecn5-7	Ecn2-4, 8, 9
Motor vehicle registration duty	Env1, 2, 8	Env3-7, 9	–	Eng1-9	Ecn4-7	Ecn2, 3, 8, 9
Motor vehicle weight tax and Green tax on passenger cars	Env2, 4, 7	Env1, 3, 5, 6, 8, 9	Eng1, 4, 7	Eng2, 3, 5, 6, 8, 9	Ecn5-7, 9	Ecn2-4, 8
Recycling fee on cars	Env1, 5, 8	Env2-4, 6, 7, 9	Eng4, 5	Eng1-3, 6-9	Ecn7	Ecn2-6, 8, 9
Road user charge	Env2, 3, 7, 9	Env1, 4-6, 8	Eng4	Eng1-3, 5-9	Ecn6, 7	Ecn2-5, 8, 9
Sale of vehicle number plates	Env1-3, 6, 8, 9	Env4, 5, 7	Eng1, 4, 5, 9	Eng2, 3, 6-8	Ecn5-7	Ecn2-4, 8, 9
Duty on certain chlorinated solvents	–	Env1-9	Eng4	Eng1-3, 5-9	Ecn6, 9	Ecn2-5, 7, 8
Duty on mineral oil products	Env2, 6, 7	Env1, 3-5, 8, 9	Eng4	Eng1-3, 5-9	Ecn6, 7, 9	Ecn2-5, 8
Duty on certain retail containers	Env7, 9	Env1-6, 8	Eng1, 4, 5	Eng2, 3, 6-9	Ecn9	Ecn2-8
Duty on CFC, HFC, PFC, and SF6	Env4, 7, 8	Env1-3, 5, 6, 9	Eng4	Eng1-3, 5-9	Ecn2, 3, 6	Ecn4, 5, 7-9
Duty on CO_2	Env4, 7, 9	Env1-3, 5, 6, 8	Eng1, 4, 5	Eng2, 3, 6-9	Ecn6	Ecn2-5, 7-9
Duty on coal	Env1-4, 6, 9	Env5, 7, 8	Eng1-6, 8, 9	Eng7	Ecn6, 9	Ecn2-5, 7, 8
Duty on disposable tableware	Env2, 4, 7	Env1, 3, 5, 6, 8, 9	Eng4, 7	Eng1-3, 5, 6, 8, 9	Ecn2, 3, 6	Ecn4, 5, 7-9
Duty on electric bulbs and fuses	–	Env1-9	Eng7	Eng1-6, 8, 9	Ecn5	Ecn2-4, 6-9
Duty on electricity	Env2-4, 6, 9	Env1, 5, 7, 8	Eng1-4, 6-9	Eng5	Ecn5-7, 9	Ecn2-4, 8
Duty on insurance on pleasure boats	Env2, 6, 7	Env1, 3-5, 8, 9	Eng4, 7	Eng1-3, 5, 6, 8, 9	Ecn2, 3, 6, 7, 9	Ecn4, 5, 8
Duty on motor vehicle insurance	Env4, 7	Env1-3, 5, 6, 8, 9	Eng4, 5	Eng1-3, 6-9	Ecn6, 9	Ecn2-5, 7, 8
Duty on natural gas	Env5, 8	Env1-4, 6, 7, 9	Eng1, 4, 7	Eng2, 3, 5, 6, 8, 9	Ecn6	Ecn2-5, 7-9
Duty on nitrogen	Env1	Env2-9	Eng4, 5, 8	Eng1-3, 6, 7, 9	Ecn2, 3, 6	Ecn4, 5, 7-9
Duty on oil pipeline	Env7	Env1-6, 8, 9	Eng4, 6	Eng1-3, 5, 7-9	Ecn2, 3, 6, 7, 9	Ecn4, 5, 8

D indicates environmental, energy, and economic security components determined by the dynamic of environmental tax; ND indicates components that are not determined by the environmental tax

Table 10 Results of Granger causality test for the dependence of environmental, energy, and economic security and sustainability indicators on environmental taxes in Belgium

Environmental tax	Environmental security indicators		Energy security indicators		Economic security indicators	
	D	ND	D	ND	D	ND
Environmental charge	Env1-3, 6, 7	Env8	Eng2, 4, 7-9	Eng1, 3, 6	Ecn2-6, 8, 9	Ecn7
Eurosticker	Env1, 2, 6, 8	Env3-5, 7, 9	Eng3, 4, 7, 9	Eng1, 2, 6, 8	Ecn2, 4, 7, 9	Ecn3, 5, 6, 8
Excise compensating tax	Env1, 3, 7	Env2, 4-6, 8, 9	Eng2, 3, 8	Eng1, 4, 6, 7, 9	Ecn2-5, 7, 9	Ecn6, 8
APETRA contribution	Env1, 2, 7	Env3, 6, 8	Eng1-4, 6, 7	Eng8, 9	Ecn2-5, 7, 8	Ecn6, 9
Contribution to heating fuels	Env1, 4, 5, 7	Env2, 3, 6, 8, 9	Eng4, 7	Eng1-3, 6, 8, 9	Ecn2-6	Ecn7-9
Excise duties on fuels and electricity	Env1, 6, 8	Env2-5, 7, 9	Eng3, 7	Eng1, 2, 4, 6, 8, 9	Ecn2, 4, 7, 9	Ecn3, 5, 6, 8
FAPETRO contribution	–	Env1-9	Eng8	Eng1-4, 6, 7, 9	Ecn2, 8	Ecn3-7, 9
The federal contribution to electricity and natural gas	Env3, 4, 7-9	Env1, 2, 5, 6	Eng1, 3, 6	Eng2, 4, 7-9	Ecn7, 8	Ecn2-6, 9
Packaging charge	Env1, 5, 8	Env2-4, 6, 7, 9	Eng7	Eng1-4, 6, 8, 9	Ecn2-5, 8	Ecn6, 7, 9
Tax on motor vehicle insurance premiums	Env1, 2, 6, 8	Env3-5, 7, 9	Eng7	Eng1-4, 6, 8, 9	Ecn2, 4, 7	Ecn3, 5, 6, 8, 9
Tax on industrial waste	Env2, 4, 5	Env1, 3, 6-9	Eng1, 6	Eng2-4, 7-9	–	Ecn2-9

D indicates environmental, energy, and economic security components determined by the dynamic of environmental tax; ND indicates components that are not determined by the environmental tax

Table 11 Results of Granger causality test for the dependence of environmental, energy, and economic security and sustainability indicators on environmental taxes in the UK

Environmental tax	Environmental security indicators		Energy security indicators		Economic security indicators	
	D	ND	D	ND	D	ND
Aggregates levy	Env2, 5, 7-9	Env1, 3, 4, 6	Eng1, 4	Eng2, 3, 5-9	Ecn2, 3, 7, 8	Ecn1, 4-6, 9
Air passenger duty	Env3, 7, 9	Env1, 2, 4-6, 8	Eng2, 3, 6, 7, 9	Eng1, 4, 5, 8	Ecn1, 2, 5-7, 9	Ecn3, 4, 8
Air travel organizer license fees	Env1, 2, 7, 8	Env3, 6	Eng2-6, 9	Eng7, 8	Ecn1, 8	Ecn2-7, 9
Climate change levy	Env5, 6, 8	Env1-4, 7, 9	Eng4, 5, 8	Eng1-3, 6, 7, 9	Ecn8	Ecn1-7, 9
Duty on hydrocarbon oils	Env2, 5-7	Env1, 3, 4, 8, 9	Eng3, 7	Eng1, 2, 4-6, 8, 9	Ecn1, 2, 9	Ecn3-8
Fishing licenses	Env2, 6, 7	Env1, 3-5, 8, 9	Eng3, 7	Eng1, 2, 4-6, 8, 9	Ecn2, 7, 9	Ecn1, 3-6, 8
Landfill tax	Env2, 3, 5-7	Env1, 4, 8, 9	Eng3, 7-9	Eng1, 2, 4-6	Ecn1, 2, 4, 7, 9	Ecn3, 5, 6, 8
Rail franchise premia	Env2	Env1, 3-9	Eng1-3, 6, 7, 9	Eng4, 5, 8	Ecn5, 7, 9	Ecn1-4, 6, 8
Rail regulator fees	Env2-4, 6, 9	Env1, 5, 7, 8	Eng1, 7	Eng2-6, 8, 9	Ecn1, 5	Ecn2-4, 6-9
Renewable energy obligations	Env3-5, 8, 9	Env1, 2, 6, 7	Eng1, 2, 3, 6, 7, 9	Eng4, 5, 8	Ecn1, 3, 6, 7, 9	Ecn2, 4, 5, 8
Vehicle excise duty	Env3, 7, 9	Env1, 2, 4-6, 8	Eng3, 7, 9	Eng1, 2, 4-6, 8	Ecn1, 2, 7, 9	Ecn3-6, 8
Water regulator fees	–	Env1-9	Eng1-4, 6, 7, 9	Eng5, 8	Ecn1, 5, 7, 9	Ecn2-4, 6, 8

D indicates environmental, energy, and economic security components determined by the dynamic of environmental tax; ND indicates components that are not determined by the environmental tax

Table 12 Results of Granger causality test for the dependence of environmental, energy, and economic security and sustainability indicators on environmental taxes in France

Environmental tax	Environmental security indicators		Energy security indicators		Economic security indicators	
	D	ND	D	ND	D	ND
Additional tax on vehicle insurances	Env3, 6, 8	Env1, 2, 4, 5, 7, 9	Eng5, 7, 8	Eng1-4, 6, 9	Ecn2, 5, 8	Ecn3, 4, 6, 7, 9
Annual tax on company cars	Env3, 7-9	Env1, 2, 4-6	Eng1, 4, 7, 8	Eng2, 3, 5, 6, 9	Ecn2, 5, 7, 8	Ecn3, 4, 6, 9
CO_2-related malus system for motor vehicle registrations (malus automobile)	Env2, 5, 7	Env1, 6, 8	Eng3-9	–	Ecn4, 6-9	Ecn2, 3, 5
Contribution of insurers of insurance guarantee funds	Env1, 4, 5	Env2, 3, 6-9	Eng1, 3, 4, 7, 8	Eng2, 5, 6, 9	Ecn5-8	Ecn2-4, 9
Tax on motorway concessions	Env1, 3, 5, 8, 9	Env2, 4, 6, 7	Eng1, 4, 7	Eng2, 3, 5, 6, 8, 9	Ecn2, 5, 9	Ecn3, 4, 6-8
Tax on registration certificates	Env3, 5, 7, 8	Env1, 2, 4, 6, 9	Eng1, 4, 7	Eng2, 3, 5, 6, 8, 9	Ecn2, 5, 7	Ecn3, 4, 6, 8, 9
Tax on the use of river waterways	Env3, 8	Env1, 2, 4-7, 9	Eng1, 3, 4, 7, 8	Eng2, 5, 6, 9	Ecn2, 5, 7	Ecn3, 4, 6, 8, 9
Tax on vehicles axles	Env1, 2, 7, 8	Env3-6, 9	Eng5, 7	Eng1-4, 6, 8, 9	Ecn2-4, 6, 9	Ecn5, 7, 8
Household refuse collection tax	Env3-5, 8, 9	Env1, 2, 6, 7	Eng1, 3, 4, 7, 8	Eng2, 5, 6, 9	Ecn2, 5, 7, 9	Ecn3, 4, 6, 8
Taxes on coal consumption	Env4, 7	Env1-3, 5, 6, 8, 9	Eng1, 4, 5, 7	Eng2, 3, 6, 8, 9	Ecn2, 5-8	Ecn3, 4, 9
Taxes on water consumption	Env3, 4, 7	Env1, 2, 5, 6, 8, 9	Eng1, 3, 4, 7	Eng2, 5, 6, 8, 9	Ecn2, 5, 7, 8	Ecn3, 4, 6, 9
Water effluent charges	Env5, 7, 8	Env1, 2-4, 6, 9	Eng1, 4, 7	Eng2, 3, 5, 6, 8, 9	Ecn2, 3, 7, 8	Ecn4-6, 9
Contribution of low-voltage electrical energy distributors	Env3, 7, 8	Env1, 2, 4-6, 9	Eng5, 7	Eng1-4, 6, 8, 9	Ecn2, 5, 7	Ecn3, 4, 6, 8, 9
Contribution to electricity generators for public services	Env1, 2, 4, 6, 9	Env3, 5, 7, 8	Eng1, 2-6	Eng7-9	Ecn3, 7-9	Ecn2, 4-6
Dock dues	Env3-5, 9	Env1, 2, 6-8	Eng1, 3, 4, 6-8	Eng2, 5, 9	–	Ecn2-9
Domestic tax on electricity final consumption	Env2-5, 8, 9	Env1, 6, 7	Eng1, 3, 4, 7	Eng2, 5, 6, 8, 9	Ecn2, 5-8	Ecn3, 4, 9
Domestic tax on natural gas	Env3, 7-9	Env1, 2, 4-6	Eng1, 4, 5, 7, 8	Eng2, 3, 6, 9	Ecn2-7	Ecn8, 9
A general tax on polluting activities	Env3, 4, 6	Env1, 2, 5, 7-9	Eng3-8	Eng1, 2, 9	Ecn3	Ecn2, 4-9
Mineral oils tax	Env3, 4, 7, 8	Env1, 2, 5, 6, 9	Eng7	Eng1-6, 8, 9	Ecn2, 5	Ecn3, 4, 6-9
Mining taxes	Env1-5, 7, 9	Env6, 8	Eng1, 4, 7, 8	Eng2, 3, 5, 6, 9	Ecn2, 3, 4, 6, 9	Ecn5, 7, 8
Special fuel tax in communities overseas	Env3, 4, 7-9	Env1, 2, 5, 6	Eng4, 5, 7, 8	Eng1-3, 6, 9	Ecn2, 5, 6, 9	Ecn3, 4, 7, 8
Tax due by airlines and shipping in overseas departments	Env3, 5	Env1, 2, 4, 6-9	Eng1-9	–	Ecn2, 5, 7	Ecn3, 4, 6, 8, 9
Tax on electricity pylons	Env3, 4, 8, 9	Env1, 2, 5, 6, 7	Eng1, 3, 4, 7, 8	Eng2, 5, 6, 9	Ecn2, 5, 7, 9	Ecn3, 4, 6, 8

D indicates environmental, energy, and economic security components determined by the dynamic of environmental tax; ND indicates components that are not determined by the environmental tax

Table 13 Results of Granger causality test for the dependence of environmental, energy, and economic security and sustainability indicators on environmental taxes in Austria

Environmental tax	Environmental security indicators		Energy security indicators		Economic security indicators	
	D	ND	D	ND	D	ND
Duty for airways security	Env3, 6, 7, 9	Env1, 2, 4, 5, 8	Eng2, 4, 7-9	Eng1, 3, 5, 6	Ecn5	Ecn2-4, 6-8
Road transport duty	Env2, 4, 6	Env1, 3, 5, 8, 9	Eng1, 2, 8, 9	Eng3-7	Ecn3, 7	Ecn2, 4, 6, 8
Car registration taxes	Env3, 7	Env1, 2, 4-6, 8, 9	Eng2, 4-9	Eng1, 3	Ecn2, 6, 9	Ecn3-5, 7, 8
Duty on vehicles (based on fuel consumption)	Env3-7	Env1, 2, 8, 9	Eng2-9	Eng1	–	Ecn2-9
Energy tax	Env3-5, 7	Env1, 2, 6, 8, 9	Eng1, 2, 7, 9	Eng3-6, 8	Ecn2, 4, 6	Ecn3, 5, 7-9
Hunting and fishing duties	Env1, 5-7	Env2-4, 8, 9	Eng3	Eng1, 2, 4-9	Ecn7, 8	Ecn2-6, 9
Motor vehicle tax	Env3, 7-9	Env1, 2, 4-6	Eng3, 4, 6, 7	Eng1, 2, 5, 8, 9	Ecn9	Ecn2-8
Recurrent taxes on motor vehicles	Env1-3, 5-7	Env4, 8, 9	Eng1, 2, 4, 7-9	Eng3, 5, 6	Ecn2, 6, 9	Ecn3-5, 7, 8
Tax on mineral oils	Env2, 3, 5-7	Env1, 4, 8, 9	Eng2, 4, 7-9	Eng1, 3, 5, 6	Ecn2, 6, 9	Ecn3-5, 7, 8
Vignette for the use of highways	Env1-3, 6, 7	Env4, 5, 8, 9	Eng1, 2, 7	Eng3-6, 8, 9	Ecn2, 6, 7, 9	Ecn3-5, 8
Waste deposit levy	Env7, 9	Env1-6, 8	–	Eng1-9	Ecn2, 4, 5, 9	Ecn3, 6-8
Fee for landscape and nature protection	Env3, 6, 7	Env1, 2, 4, 5, 8, 9	Eng2, 5, 7, 9	Eng1, 3, 4, 6, 8	Ecn2, 4, 6, 9	Ecn3, 5, 7, 8
Fee on municipal waste collection/treatment	Env5, 6, 8, 9	Env1-4	Eng2, 5, 7, 9	Eng1, 3, 4, 6, 8	Ecn3, 8	Ecn2, 4, 6, 7
Fee on water use	Env2, 3, 6	Env1, 4, 5, 7-9	Eng1, 2, 4, 5, 7, 9	Eng3, 6, 8	Ecn2, 6	Ecn3-5, 7-9
Road pricing for lorries for the use of highways	Env3-7, 9	Env1, 2, 8	Eng2-4, 7, 8	Eng1, 5, 6, 9	Ecn2, 3, 5, 6, 9	Ecn4, 6, 8
The toll for specific routes on highways	Env3	Env1, 2, 4-9	Eng2, 4, 5, 7, 9	Eng1, 3, 6, 8	Ecn5, 9	Ecn2-4, 6-8
Wastewater charges	Env2, 4, 7	Env1, 3, 5, 6, 8, 9	Eng1, 2, 5, 7, 9	Eng3, 4, 6, 8	Ecn4, 5, 6, 8	Ecn2, 3, 7

D indicates environmental, energy, and economic security components determined by the dynamic of environmental tax; ND indicates components that are not determined by the environmental tax

Table 14 Results of Granger causality test for the dependence of environmental, energy, and economic security and sustainability indicators on environmental taxes in Finland

Environmental tax	Environmental security indicators		Energy security indicators		Economic security indicators	
	D	ND	D	ND	D	ND
Fishing license fees	Env1, 3-8	Env2, 9	Eng3, 4, 7	Eng1, 2, 6, 8, 9	Ecn2, 6, 9	Ecn3-5, 7, 8
Car tax	Env1, 3, 4, 6	Env2, 5, 7-9	Eng2, 3, 6, 8, 9	Eng1, 4, 7	Ecn2, 5	Ecn3, 4, 6-9
Charge on tires	Env3, 5-9	Env1, 2, 4	Eng1-4, 6-9	–	Ecn2, 5, 6	Ecn3, 4, 7-9
Excise on beverage containers	Env4, 6	Env1-3, 5, 7-9	Eng4, 8	Eng1-3, 6, 7, 9	Ecn2-4, 6-8	Ecn5, 9
Excise on fuels and electricity	Env3-5, 7, 8	Env1, 2, 6, 9	Eng2-4, 6, 7, 9	Eng1, 8	Ecn2, 3, 5, 6, 9	Ecn4, 7, 8
Fairway fee (channel fee)	Env1, 6, 8	Env2-5, 7, 9	Eng1, 6, 8	Eng2-4, 7, 9	Ecn4, 7, 9	Ecn2, 3, 5, 6, 8
Hunting license fees	Env4-8	Env1-3, 9	Eng7	Eng1-4, 6, 8, 9	Ecn2, 3, 6, 9	Ecn4, 5, 7, 8
Nuclear energy research levy	Env1-3, 5, 7-9	Env4, 6	Eng1-4, 6, 7, 9	Eng8	Ecn5	Ecn2-4, 6-9
Oil damage levy	Env3, 5, 7-9	Env1, 2, 4, 6	Eng2-4, 6, 7, 9	Eng1, 8	Ecn2, 6, 7	Ecn3-5, 8, 9
Oil waste levy	Env3-5	Env1, 2, 6-9	Eng4	Eng1-3, 6-9	Ecn2, 3, 6, 7, 9	Ecn4, 5, 8
Railway tax	Env2, 4-6	Env1, 3, 7-9	–	Eng1-9	–	Ecn2-9
Registration fee of vehicles	Env3-8	Env1, 2, 9	Eng2-4, 6-9	Eng1	Ecn2, 6, 9	Ecn3-5, 7, 8
Strategic stockpile fee	Env3, 5, 6	Env1, 2, 4, 7-9	Eng4	Eng1-3, 6-9	Ecn2, 5, 7	Ecn3, 4, 6, 8, 9
Tax on waste	Env4, 6, 8	Env1-3, 5, 7, 9	Eng4, 7, 8	Eng1, 2, 3, 6, 9	Ecn2	Ecn3-9
Vehicle tax	Env2-5, 9	Env1, 6-8	Eng1-4, 6-9	–	Ecn2, 5, 6, 9	Ecn3, 4, 7, 8
Charge on municipal waste collection	Env3-8	Env1, 2, 9	Eng2-4, 9	Eng1, 6-8	Ecn2, 6, 9	Ecn3-5, 7, 8
Charge on nuclear waste	Env3, 5, 7-9	Env1, 2, 4, 6	Eng2-4, 6, 7	Eng1, 8, 9	Ecn2, 6, 7	Ecn3-5, 8, 9
Fishery management fee	Env4, 5	Env1-3, 6-9	Eng2, 4	Eng1, 3, 6-9	Ecn2, 3, 6, 8, 9	Ecn4, 5, 7
Railway fee	Env3, 5, 7, 9	Env1, 2, 4, 6, 8	Eng1, 2, 4, 6, 8	Eng3, 7, 9	Ecn2	Ecn3-9
Wastewater user charges	Env4-6	Env1-3, 7-9	Eng2, 4, 9	Eng1, 3, 6-8	Ecn2, 6, 7, 9	Ecn3-5, 8
Water user charges	Env3-6	Env1, 2, 7-9	Eng2, 4, 7, 9	Eng1, 3, 6, 8	Ecn2, 5-7, 9	Ecn3, 4, 8

D indicates environmental, energy, and economic security components determined by the dynamic of environmental tax; ND indicates components that are not determined by the environmental tax

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